UCLA Stat 130D
Statistical Computing and Visualization in C++

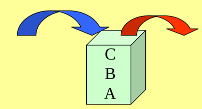
Instructor: **Ivo Dinov**, Asst. Prof. in Statistics / Neurology

University of California, Los Angeles, Winter 2007

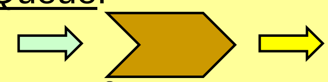
http://www.stat.ucla.edu/~dinov/courses_students.html

Review of Data Structures

LIFO – stack:

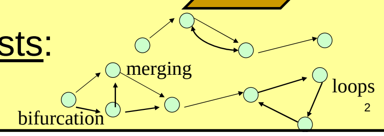


FIFO – Deck/Queue:



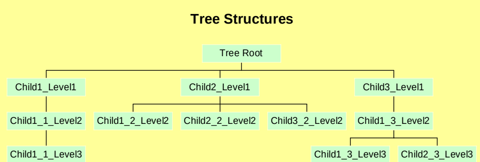
Linked-Lists:

Graphs:

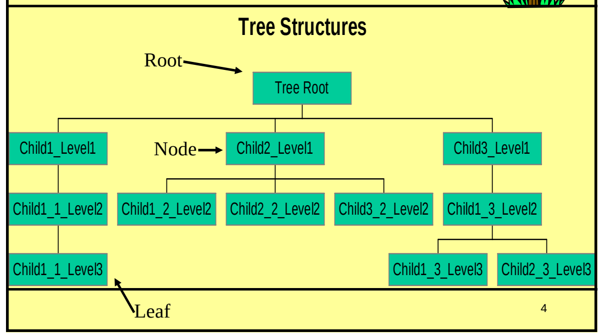


Trees

- Trees are important in design and analysis of algorithms
  - Useful in describing dynamic properties of algorithms
  - We build and use data structures which are direct realizations of trees (Genotypic evolutionary organization of species)
  - Ancestor-Descendants data organization (SuperClass→SubClass)
  - Hierarchical organization (computer folder/directory organization)



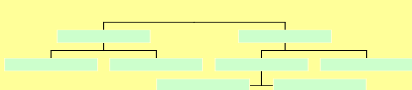
Trees



Trees

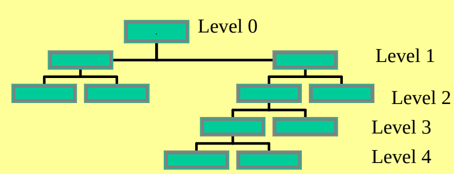
- Tree – non-empty collection of vertices and edges, satisfying:

  A vertex is a node that has a name; An edge is a connection between two nodes. A path in a tree is a collection of distinct vertices in which successive vertices are connected by edges in the tree. There is precisely one path connecting two nodes in every tree. No loops allowed.
- Ordered trees – the order of the children of each node is important.
- Binary trees – ordered tree where each node has either 2 or no children.



Binary Trees

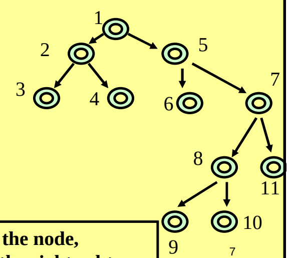
- Properties of binary trees
  - A binary tree with N internal (non-terminal) nodes has exactly (N+1) external (leaves) nodes.
  - A binary tree with N internal (non-terminal) nodes has exactly 2N edges.



Tree Traversal - Preorder

- Tree traversal is the process of systematically processing each node in the tree given a pointer to its root. For binary trees, traversal could be accomplished recursively:
- void PreOrderTraverse (link home)

```
{       process_current_node();
        if (home==NULL)  return;
        PreOrderTraverse(h→left);
        PreOrderTraverse(h→right);
}
```

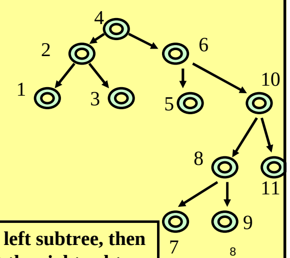


Preorder traversing – visit the node, then visit the left and then the right subtrees.

Binary Tree Traversal - Inorder

- void InOrderTraverse (link home)

```
{ if (home==NULL)  return;
     InOrderTraverse(h→left);
     process_current_node();
     InOrderTraverse(h→right);
}
```

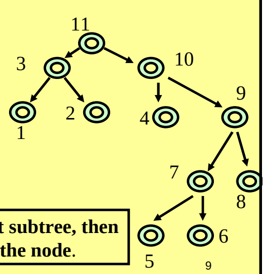


Inorder traversing – visit the left subtree, then visit the node and finally visit the right subtree.

Tree Traversal - Postorder

- void PostOrderTraverse (link home)

```
{ if (home==NULL)  return;
     PostOrderTraverse(h→left);
     PostOrderTraverse(h→right);
     process_current_node();
}
```



Postorder traversing – visit the left subtree, then visit the right subtree, finally visit the node.

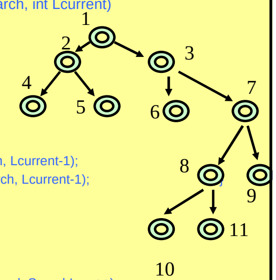
Level-order traversing – visit all nodes, one level at a time, top-to-bottom, as they appear on the graph.

- void LevelOrderTraverse (link home, int Lsearch, int Lcurrent)

```
{       if (home==NULL)  return;
        Node nodeLeft = home→linkLeft;
        Node nodeRight = home→linkRight;
        if (Lcurrent==Lsearch-1)
        {  process_current_node(nodeLeft );
            process_current_node(nodeRight );
        }
        else if (Lcurrent<Lsearch-1)
        {  LevelOrderTraverse(nodeLeft, Lsearch, Lcurrent-1);
            LevelOrderTraverse(nodeRight, Lsearch, Lcurrent-1);
        else return;
}
```

- void main ()

```
{       // define TREE structure etc.
         process_current_node(Root);
        for (int SearchLev = 1; SearchLev < max_Level; SearchLev ++)
        {  LevelOrderTraverse (root, SearchLev , 0);  }
}
```



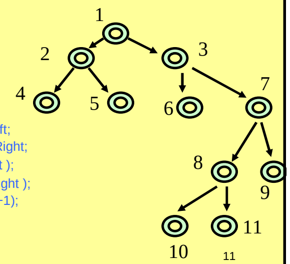
Tree Traversal

Computing the number of nodes in a tree

```
int numberOfNodes (link h)        // Use any traversing algorithm and count Nodes
{  if (home==NULL)  return 0;
     return numberOfNodes(h→l) +
            numberOfNodes(h→r) +1;
}
```

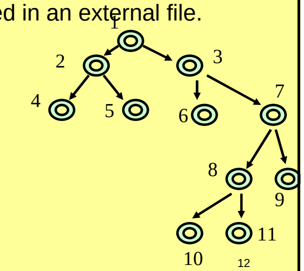
Computing the height of a tree

```
int treeHeight(link h)
{  if (home==NULL)  return 0;
     else {        Node nodeLeft = home→linkLeft;
                   Node nodeRight = home→linkRight;
                   int leftH = treeHeight(nodeLeft );
                   int rightH = treeHeight(nodeRight );
                   if (leftH >= rightH) return (leftH+1);
                   else return (rightH+1);
            }
}
```



Brain Tree Example

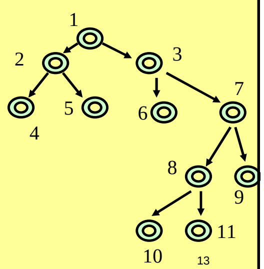
- Write a program that reads/writes/displays a brain-tree where the nodes are saved in an external file.



Tree Class

- Write a <u>prototype</u> for a Tree Node class.
- class TreeNode

```
{  public:
        TreeNode();
        TreeNode(TreeNode&);
        TreeNode(string);
        TreeNode(char*);
        ~TreeNode();
        TreeNode&  getParent();
        void setParent(TreeNode&);
        string getAuxInfo();
        void setAuxInfo (string);
        string getName();
        void setName(string);
        void setName(char*);
   private:   TreeNode* parent;
        string name;
        string* aux_info;
};
```



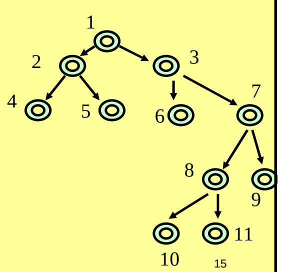
Tree Class

- Write a prototype for a Tree Node class.

```
TreeNode::TreeNode()
{    parent = NULL; setName("");    setAuxInfo("");   }

TreeNode::TreeNode(TreeNode& N)
{ parent = N;  setName("");    setAuxInfo("");   }

TreeNode::TreeNode(string s)
{ parent = NULL;  setName(s);    setAuxInfo(""); }

TreeNode:: TreeNode(char* ch)
{ parent = NULL;   setName(ch);  setAuxInfo("");   }

TreeNode:: ~TreeNode()
 {   delete [ ] parent;   delete [ ] aux_info;    }
```


Tree Class

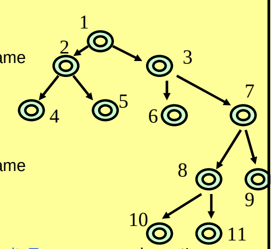
```
TreeNode::TreeNode& getParent()
{   return  parent;   }

TreeNode void setParent(TreeNode&)
{   parent = P;   }

TreeNode:: string getName()
{   return name;   }

TreeNode:: void setName(string str)
{   name = str;   }

TreeNode:: void setName(char* ch)
{   name = new string(ch);     }

TreeNode:: string getAuxInfo()
{   return aux_info;    }

TreeNode:: void setAuxInfo (string str)
{   aux_info  =  str}
```



Tree Class

Perhaps we need two additional methods for <u>Reading/Writing</u> The TREE structure out to a file;

```
class TreeNode
 {   public:
            friend int readTree(string);
      // Pre:: string contains a valid file name
      //       containing a Tree structure
      // Post:: returns 0 if reading/parsing
      //      the file okay, !=0 otherwise

            friend int writeTree(string);
      // Pre:: string contains a valid file name
      //       accessible for writing
      // Post:: returns 0 if writing out Tree
      //      went okay, !=0 otherwise
 }
```



<u>// Recursive</u> implementations of readTree/writeTree are <u>very elegant</u>!
Show BrainTree example (java-based)

Sorting Methods

- Sorting Objects
  - Disc/Tape Filename sorting (external, disc block-size)
  - Array sorting (internal, fits in memory, in general)
  - File content sorting (Excel spreadsheet column/row sorting)
- Sorting Efficiency
  - O(N^2)   vs. O(N logN)

"*Big-Oh*" notation, e.g., O(n Log(n))

- We say that the <u>complexity of an algorithm</u> is O(f(n)), <u>if and only if</u> the ratio

$$g(n) \le Const * f(n), \forall n > N_o \qquad \frac{g(n)}{f(n)} \xrightarrow{n \to \infty} \text{constant}$$

- Where g(n) is the actual *number of operations* the algorithm needs to perform to complete the solution to the problem, and f(n) is some known (say polynomial) function.
- *Big-Oh* provides a <u>bound for the asymptotic model</u> for the real computational complexity of an algorithm.

“*Big-O*” notation, e.g., O(n Log(n))

- For example, linear search for the smallest element in an (unordered) array is *O(n),* since we roughly need to perform (n-1) comparisons to determine the smallest element

```
min = a[0];
for (int I=1; I<n; I++)
{  if (a[I] < min) min = a[I];
}
```

Actual number of comparisons: n-1

$$\frac{n-1}{n} \xrightarrow[n\to\infty]{} 1$$

Comparison Poly Factor, in O(n)

Conditional statements are inexpensive!

Simple array sorting

Design an array sorting program, <u>any array type</u> with defined (order) operations < and >


```
#include <iostream.h>
#include <stdlib.h>
template <class Item>  void swap(Item &A, Item &B)
   { Item t = A; A = B; B = t; }
template <class Item>  void compexch(Item &A, Item &B)
   { if (B < A) swap(A, B); }
template <class Item>  void sort(Item a[], int l, int r)
   { for (int i = l+1; i <= r; i++)
       for (int j = i+1; j <= r; j++)     compexch( a[ i ], a[ j ] );
   }

int main(int argc, char *argv[])                          // sorts an array Min → Max
 { int i, N = atoi(argv[1]), sw = atoi(argv[2]);
   int *a = new int[N];
   if (sw)    for (i = 0; i < N; i++)     a[i] = 1000*(1.0*rand()/RAND_MAX);
   else    { N = 0;          while (cin >> a[N]) N++;        }
   sort(a, 0, N-1);
   for (i = 0; i < N; i++) cout << a[i] << " ";
   cout << endl;
 }
```

What’s the complexity of the <u>sort</u> method?

```
template <class Item>  void sort(Item a[], int l, int r)
   { for (int i = l+1; i <= r; i++)
        for (int j = i+1; j <= r; j++)  compexch(a[ j ], a[ i ]);
   }
```

Complexity of this algorithm is ::

(N-1)+(N-2) + …+2+1 ~ (N^2)/2

If N=1000, (N^2)/2 ~1,000,000/2 = 500,000

Vs. the most-efficient NlogN algorithm: NlogN~3,000

quite a significant difference. This is <u>NOT an efficient</u> sorting algorithm.

Too many swap-calls (complexch(type, type))

Selection Sort Algorithm - the current element is tested to the smallest element found so far. At most (N-1) swaps are needed to complete. N^2/2 comparisons and N exchanges

```
template <class Item>
void selectionSort(Item a[], int l, int r)
 { for (int i = l; i < r; i++)
    { int min = i;

      for (int j = i+1; j <= r; j++)
        if (a[j] < a[min]) min = j;

      swap(a[i], a[min]);             // At most N swaps
    }
 }
```

Insertion Sort Algorithm – consider the elements one at a time and insert them in the list of the already sorted elements by <u>making room and shifting all larger ones</u>.

N^2/4 comparisons and N^2/4 exchanges

```
template <class Item>
void insertionSort(Item a[], int l, int r)
 { int i;
   for (i = r; i > l; i--)   compexch(a[i-1], a[i]);
                    // puts smallest element on position 0
   for (i = l+2; i <= r; i++)
    { int j = i; Item v = a[i];    //assignment instead of exchange
      while (v < a[j-1])  {    a[j] = a[j-1];    j--;      }
      a[j] = v;
    }
 }
```

Elements to the left of current index are sorted (min→max). But they are not in final positions

Bubble Sort Algorithm – keep passing through the list exchanging adjacent elements which are out of order, continue until the entire list is sorted. (Not very efficient!)

N^2/2 comparisons and N^2/2 exchanges

```
template <class Item>
void bubbleSort(Item a[], int l, int r)
 { for (int i = l; i < r; i++)
     for (int j = r; j > i; j--)
       compexch(a[j-1], a[j]);
 }
```

Quick Sort Algorithm – array is processed by a partition procedure which puts a[i] into position for some 1<=i<=r and rearranges the other elements so that the recursive calls properly finish the quick-sort. The key is in the partition algorithm since it positions a[i] exactly at the right spot right away: <u>a[1],…,a[i-1]<= a[i] <=a[i+1],...,a[r].</u>

```
template <class Item>
void quickSort(Item a[], int l, int r)              // recursive design
 {
   if (r <= l) return;
   int i = partition(a, l, r);
   quickSort(a, l, i-1);
   quickSort(a, i+1, r);
 }
```

<u>Conditions:</u>

1. Partitioning makes a[I] be in final position, for some I.
2. All a[l], …, a[I-1] <= a[I].
3. All a[I+1], …, a[r] >= a[I].

Quick Sort – Core partition method

Computational Complexity:

1. **Most of time: N log(N)**
2. **Worst cases: N²**

```
template <class Item>
int partition(Item a[], int l, int r)
 { int i = l-1, j = r;                    Item v = a[r];
   for (;;)   // infinite loop, terminates when break is called
              //   only when the two pointers cross!
    { while (a[++i] < v) ;          //  i→,   and ←j
      while (v < a[--j])       if (j == l) break;
      if (i >= j) break;
      swap(a[i], a[j]);
    }
   swap(a[i], a[r]);
   return i;
 }
```

<u>Strategy:</u>

1. Arbitrary choose a[r] to be the *partitioning element* to go in its final position.
2. Scan from left until we find element grater than a[r]. Scan from right to find element less then a[r].
3. These two elements are obviously out-of-order – swap them and continue.

Merging and MergeSort – combine two <u>ordered</u> arrays into one ordered array.

```
template <class Item>
void merge_AB(Item c[], Item a[], int N, Item b[], int M )
 {
   for (int i = 0, j = 0, k = 0; k < N+M; k++)
    {
      if (i == N) { c[k] = b[j++]; continue; }
      if (j == M) { c[k] = a[i++]; continue; }
      c[k] = (a[i] < b[j]) ? a[i++] : b[j++];  // ternary
   comparison
    }
 }
```

<u>Template Example of Linked List Class</u>

```
#ifndef H_LinkedListType
#define H_LinkedListType

#include <iostream>
using namespace std;

template <class Type>
struct NodeType
{
   Type info;
   NodeType<Type> *link;
};
```


<u>Template Example of Linked List Class</u>

```
template<class Type>
class LinkedListType
{
public:
   // constructors
   LinkedListType();
   LinkedListType(const LinkedListType<Type>&
otherList);
   ~LinkedListType();

   // observers
   const LinkedListType<Type>& operator=
                     (const
   LinkedListType<Type>&);
   bool IsEmptyList();
   bool IsFullList();
   void Print();
   int  Length();
   void RetrieveFirst(Type& firstElement);
   void Search(const Type& searchItem);
```

Template Example of Linked List Class

```
   // transformers
   void InitializeList();
   void DestroyList();
   void InsertFirst(const Type& newItem);
   void InsertLast(const Type& newItem);
   void DeleteNode(const Type& deleteItem);

private:
   NodeType<Type> *first;
   NodeType<Type> *last;
};

#endif
```


Template Example of Linked List Class

```
#include "linkedlist.h"
using namespace std;

template<class Type>
LinkedListType<Type>::LinkedListType()
{
   first = NULL;
   last = NULL;
}
```


Template Example of Linked List Class

```
template<class Type>
LinkedListType<Type>::LinkedListType(
   const LinkedListType<Type>& otherList)
{
    NodeType<Type> *newNode;
    NodeType<Type> *current;

    if(otherList.first == NULL)
    {
        first=NULL;
        last=NULL;
    }
```


Template Example of Linked List Class

```
    else
    {
         current = otherList.first;
        first = new NodeType<Type>;
        first->info = current->info;
        first->link = NULL;
        last = first;
        current = current->link;
        while(current != NULL)
         {
              newNode = new NodeType<Type>;
              newNode->info = current->info;
              newNode->link = NULL;
              last->link = newNode;
              last = newNode;
              current = current->link;
        }
   }
}
```


Template Example of Linked List Class

```
template<class Type>
LinkedListType<Type>::~LinkedListType()
{
   NodeType<Type> *temp;

   while(first != NULL)
    {
         temp = first;
         first = first->link;
         delete temp;
   }

   last = NULL;
}
```


Template Example of Linked List Class

```
template<class Type>
const LinkedListType<Type>&
LinkedListType<Type>::operator=(
   const LinkedListType<Type>& otherList)
{
   NodeType<Type> *newNode;
   NodeType<Type> *current;

   if(this != &otherList)
   {
         if(first != NULL)
               DestroyList();

         if(otherList.first == NULL)
         {
               first = NULL;
               last = NULL;
         }
```

Template Example of Linked List Class

```
    else
    {           current = otherList.first;
                first = new NodeType<Type>;
                      first->info = current->info;
                      first->link = NULL;

                last = first;
                current = current->link;
                while(current != NULL)
                {
                      newNode = new NodeType<Type>;
                      newNode->info = current->info;
                      newNode->link = NULL;
                      last->link = newNode;
                      last = newNode;
                      current = current->link;
                }
          }
    }
    return *this;
}
```


Template Example of Linked List Class

```
template<class Type>
bool LinkedListType<Type>::IsEmptyList()
{
   return(first == NULL);
}

template<class Type>
bool LinkedListType<Type>::IsFullList()
{
   return false;
}
```


Template Example of Linked List Class

```
template<class Type>
void LinkedListType<Type>::Print()
{
   NodeType<Type> *current;

   current = first;
   while(current != NULL)
   {
      cout<<current->info<<" ";
      current = current->link;
   }
}
```


Template Example of Linked List Class

```
template<class Type>
int LinkedListType<Type>::Length()
{
   int count = 0;
   NodeType<Type> *current;

   current = first;
   while (current!= NULL)
   {
      count++;
      current = current->link;
   }

   return count;
}
```


Template Example of Linked List Class

```
template<class Type>
void
LinkedListType<Type>::RetrieveFirst(Type&
        firstElement)
{
   firstElement = first->info;
}
```


Template Example of Linked List Class

```
template<class Type>
void LinkedListType<Type>::Search(const Type& item)
{
   NodeType<Type> *current;
   bool found;

   if(first == NULL)
         cout<<"Cannot search an empty list. "<<endl;
   else {
         current = first;
         found = false;
         while(!found && current != NULL)
               if(current->info == item) found = true;
               else current = current->link;
         if(found)
               cout<<"Item is found in the list."<<endl;
         else
               cout<<"Item is not in the list."<<endl;
   }
}
```

Template Example of Linked List Class

```
template<class Type>
void LinkedListType<Type>::InitializeList()
{
   DestroyList();
}

template<class Type>
void LinkedListType<Type>::DestroyList()
{
   NodeType<Type> *temp;

   while(first != NULL) {
      temp = first;
      first = first->link;
      delete temp;
   }
   last = NULL;
}
```


Template Example of Linked List Class

```
template<class Type>
void LinkedListType<Type>::InsertFirst(const
Type& newItem) {
   NodeType<Type> *newNode;

   newNode = new NodeType<Type>;
   newNode->info = newItem;
   newNode->link = first;
   first = newNode;
   if(last == NULL)
        last = newNode;
}
```


Template Example of Linked List Class

```
template<class Type>
void LinkedListType<Type>::InsertLast(const
Type& newItem)
{
    NodeType<Type> *newNode;

   newNode = new NodeType<Type>;
    newNode->info = newItem;
    newNode->link = NULL;
   if(first == NULL){
        first = newNode;
        last = newNode;
   }
   else
   {    last->link = newNode;
        last = newNode;
   }
}
```


Template Example of Linked List Class

```
template<class Type>
void LinkedListType<Type>::deleteNode
   (const Type & deleteItem)
{
   NodeType<Type> *current;
   NodeType<Type> *trailCurrent;
   bool found;

   if(first == NULL)
      cout<<"Can not delet,empty list.\n";
   else
   {    if(first->info == deleteItem)
        {
             current = first;
             first = first ->link;
             if(first == NULL) last = NULL;
             delete current;
        }
```


Template Example of Linked List Class

```
else
{  found = false;
   trailCurrent = first;
   current = first->link;

   while((!found) && (current != NULL))
   {
        if(current->info != deleteItem)
        {
             trailCurrent = current;
             current = current-> link;
        }
        else found = true;
   }
```


Template Example of Linked List Class

```
      if(found) {
         trailCurrent->link = current->link;
         if(last == current)
              last = trailCurrent;
         delete current;
      }
      else cout<<"Item is not in list.\n“;
    }
  }
}
```

Template Example of Linked List Class

```
template<class Type>
const LinkedListType<Type>&
LinkedListType<Type>::operator=(
   const LinkedListType<Type>& otherList)
{
   NodeType<Type> *newNode;
   NodeType<Type> *current;

   if(this != &otherList)
   {  if(first != NULL)
            DestroyList();
      if(otherList.first == NULL)
      {
            first = NULL;
            last = NULL;
      }
```


Template Example of Linked List Class

```
      else
      {
            current = otherList.first;
            first = new NodeType<Type>;
            first->info = current->info;
            first->link = NULL;
            last = first;
            current = current->link;
```


Template Example of Linked List Class

```
            while(current != NULL)
            {
                  newNode = new NodeType<Type>;
                  newNode->info = current->info;
                  newNode->link = NULL;
                  last->link = newNode;
                  last = newNode;
                  current = current->link;
            }
      }
   }

   return *this;
}
```


Template Example of Linked List Class

```
#include <iostream>
#include "linkedlist.h"
using namespace std;

int main(){
   LinkedListType<int> list1, list2;
   int num;

   cout<<"Line 3: Enter numbers ending with -999"
<<endl;
   cin>>num;

   while(num != -999) {
         list1.InsertLast(num);
         cin>>num;
   }
   cout<<endl;
```


Template Example of Linked List Class

```
   cout<<"Line 9: List 1: ";
   list1.Print();
   cout<<endl;

   cout<<"Line 12: Length List 1:
"<<list1.Length()<<endl;
   list2 = list1;
   cout<<"Line 16: List 2: ";
   list2.Print();
   cout<<endl;

   cout<<"Line 17: Length List 2: "<<list2.Length()
<<endl;

   cout<<"Line 18: Enter the number to be "
<<"deleted: ";
   cin>>num;
   cout<<endl;
```


Template Example of Linked List Class

```
   list2.DeleteNode(num);
   cout<<"Line 22: After deleting the node,"
       <<"List 2: "<<endl;
   list2.Print();
   cout<<endl;

   cout<<"Line 25: Length List 2: "
       <<list2.Length() <<endl;

   return 0;
}
```

Makefile

```
# project linked list
demo : demo.o linkedlist.o
        CC -o demo demo.o linkedlist.o
demo.o : demo.cc linkedlist.h
        CC -c demo.cc
linkedlist.o : linkedlist.cc
linkedlist.h
        CC -c linkedlist
clean :
        rm -rf *.o
```



```
Line 3: Enter numbers ending with -999
1 67 23 75 -999

Line 9: List 1: 1 67 23 75
Line 12: Length List 1: 4
Line 16: List 2: 1 67 23 75
Line 17: Length List 2: 4
Line 18: Enter the number to be deleted: 23

Line 22: After deleting the node, List 2:
1 67 75
Line 25: Length List 2: 3
```